Global Sea Level Observations
The University of Hawaii Sea Level Center

Mark A. Merrifield
University of Hawaii
Honolulu, Hawaii

PROJECT SUMMARY

The University of Hawaii Sea Level Center (UHSLC) collects, processes, analyzes, and distributes tide gauge data from around the world in support of climate and oceanographic research. The UHSLC focuses on the collection of high frequency measurements that are available in near-real time usually via the Global Telecommunications System (GTS). The center complements the Permanent Service for Mean Sea Level (PSMSL), which is the primary archive for historic monthly-averaged time series of sea level. Data are provided to the UHSLC from ~ 450 stations maintained by 65 international agencies. In addition, the UHSLC directly assists host countries in the maintenance and operation of 59 stations, including 7 stations with colocated GPS for monitoring land motion at the tide gauge. The UHSLC is an active contributor to the Intergovernmental Oceanographic Commission Global Sea Level Observing System (GLOSS), and participates in operational and scientific oversight through the GLOSS Group of Experts. The UHSLC is primarily concerned with the implementation of the Global Climate Observing System (GCOS) sea level network, a subset of GLOSS designated as particularly important for climate research.

The UHSLC distributes near real-time and historic data directly from its host web site, http://uhslc.soest.hawaii.edu, through a dedicated OPeNDAP server, the Pacific Marine Environmental Laboratory Climate Data Portal, the National Ocean Partnership Program (NOPP) sponsored National Virtual Ocean Data System (NVODS) project, and the NOAA Observing Systems Architecture (NOSA) geospatial and geospatial metadata databases. The center also collaborates with NOAA's National Oceanographic Data Center (NODC) to maintain the Joint Archive for Sea Level (JASL), which is a quality assured database of hourly sea level from selected global stations.

UHSLC datasets are used in conjunction with operational numerical models, for the calibration of satellite altimeter data, the production of oceanographic products, and research on interannual to decadal climate fluctuations and short-term extreme events. UHSLC station data are made available directly to the Pacific Tsunami Warning Center and the Japanese Meteorological Agency for tsunami monitoring, as well as to various national tsunami warning agencies. Over the years the UHSLC has participated in national and international programs including NORPAX, TOGA, WOCE, GODAE and CLIVAR.

ACCOMPLISHMENTS

Tide Gauge Operations

The UHSLC assists with the operation and maintenance of 59 international tide gauge stations in collaboration with local operators (Figure 1). All of these stations transmit data via the GOES, Meteosat, or GMT satellites. The transmission cycles have historically been between 1 to 3 hours of 2 to 6 minute averaged data; however, we are in the process of switching all stations over to 5 to 15 minute transmissions of 1 to 3 minute averages, with even higher rates at major tsunami generation zones. Of the 59 UHSLC stations, 46 contribute to the GLOSS Core network, and 32 to the GCOS network. 7 are equipped with co-located GPS, and 14 are within 10 km of a continuous GPS reference site. The UHSLC shares responsibility for the sites with local operators, which lowers our costs by reducing travel for our technicians while raising the reliability of the stations and the data quality. At most locations, on-site personnel perform regular maintenance, tide staff measurements, and provide security. UHSLC's role has been to provide spare parts as needed, to visit the sites on 1-3 year intervals to repair and upgrade components and to ensure the proper operation of the station, to trouble-shoot problems as they arise in coordination with local operators, and to quality assess the datasets.

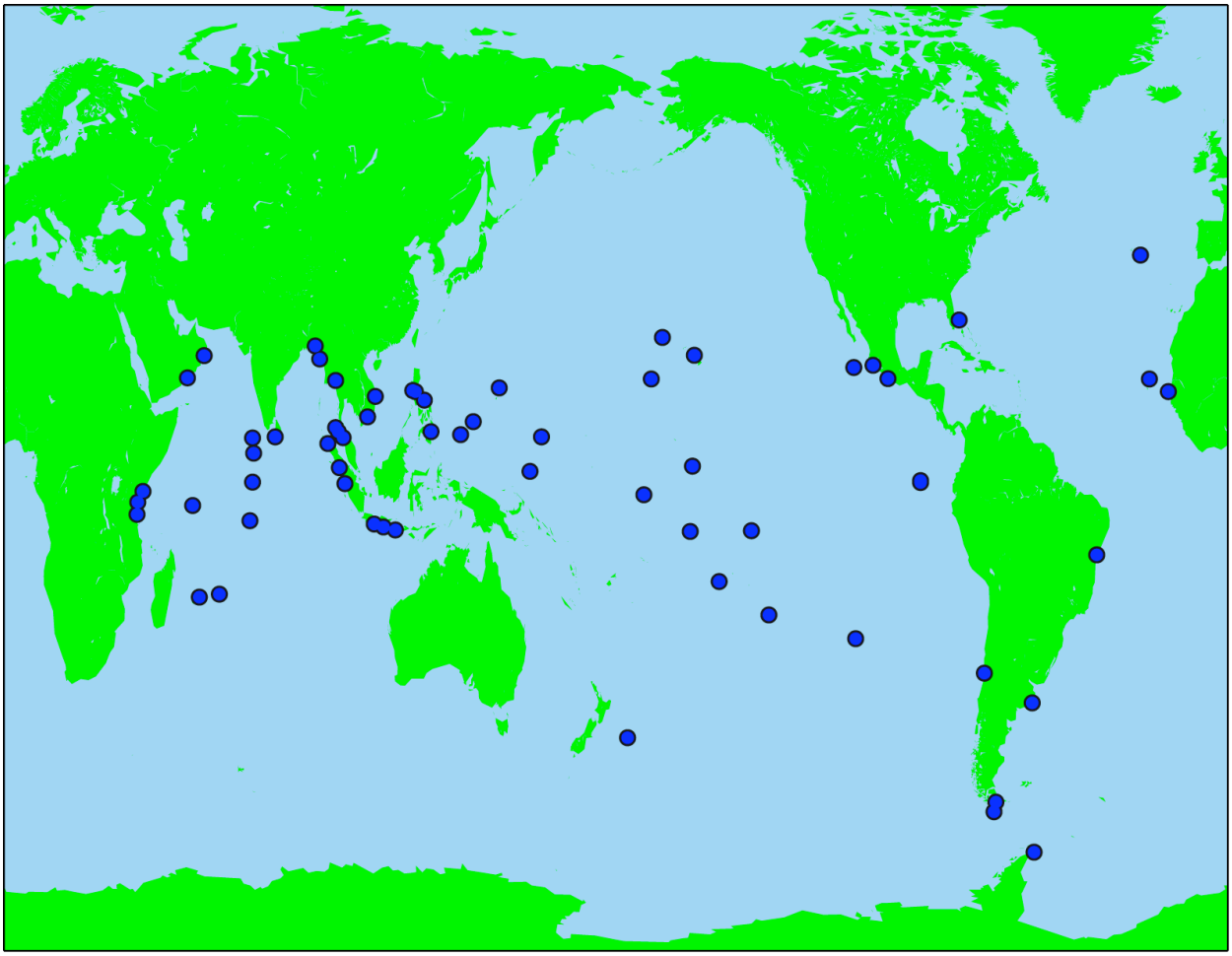

Figure 1. Tide gauge stations operated and maintained with assistance from the UHSLC.

New station installations and upgrades of existing OCO stations during November 2006 through October 2007 are listed in Table 1. Five stations involved substantial financial support from co-sponsoring agencies (the Intergovernmental Oceanographic Commission, IOC; the Asian Disaster Preparedness Center, ADPC). Our ability to accomplish these installations at low costs to the co-sponsors was due to our core operational support provided by OCO. In turn, our involvement in this implementation benefited the aims of the global sea level network and OCO by ensuring that all stations are suitable for sea level monitoring as well as tsunami warning. All are equipped with open-air radar sensors, and most feature a backup float gauge or acoustic sensor, for stable and accurate long-term measurements. All of these sites are either in the GLOSS Core Network or they will be proposed as new additions to the network at the next GLOSS meeting. In addition, we intend to recommend many of these sites as replacements for nearby GCOS stations that have a low probability of becoming operational.

Station	**Country**	**Date of Visit**	**Co-Sponsor**
Christmas Island	Kiribati	2006/11	
Sibolga	Indonesia	2007/02	
Cilacap	Indonesia	2007/02	
Prigi	Indonesia	2007/02	
Saipan	N. Marianas Is.	2007/02	
Subic Bay	Philippines	2007/02	ADPC
Davao	Philippines	2007/02	
Kanton	Kiribati	2007/03	
Acapulco	Mexico	2007/05	
Manzanillo	Mexico	2007/05	
Tern Island	USA	2007/05	
Moulmein	Myanmar	2007/06	IOC
Chittagong	Bangladesh	2007/06	IOC
Penhryn	Cook Islands	2007/08	
Rikitea	Fr. Polynesia	2007/09	
Papeete	Fr. Polynesia	2007/09	
Malakal	Palau	2007/09	
Yap	Fed. Micronesia	2007/09	
Nuku Hiva	Fr. Polynesia	2007/09	
Qui Nhon	Vietnam	2007/10	ADPC
Vung Tau	Vietnam	2007/10	ADPC
Dakar	Senegal	2007/10	
Palmeira	Cape Verde	2007/10	

Dataset Holdings

The Joint Archive for Sea Level (data latency: 1-2 years) is a collaborative effort between the National Oceanographic Data Center (NODC), the World Data Center-A for Oceanography, and the UHSLC. A NOAA Liaison officer supported by National Coastal Data Development Center (NCDDC) helps maintain the JASL. The JASL consists of a quality assured database of hourly sea level time series from stations around the world. We consider this to be our research quality database, complementary to the monthly averaged data maintained as PSMSL. In the past year, the UHSLC increased its JASL holdings to 11,460 station-years, including 6,870 station-years at 232 GLOSS sites. The 2007 submission of the JASL data to the World Data Center-A for

Oceanography included 161 series that contained measurements through the year 2005, and 49 series through 2006.

The UHSLC maintains a fast delivery database (data latency: 1 month) in support of various national and international programs (e.g., GODAE, CLIVAR, GLOSS, GCOS). To ensure active participation and coordination with the international community, the database has been designated by the IOC as a component of the GLOSS program. The fast delivery data are used extensively by the altimeter community for ongoing assessment and calibration of satellite altimeter datasets. In particular, fast delivery data are used for monitoring the latest JASON altimeter and for the tie between JASON, TOPEX/Poseidon, ERS, and GEOSAT satellites. The fast delivery sea level dataset now includes 217 stations, 176 of which are located at GLOSS sites, and 119 at GCOS sites.

We consider a fully operational network to have near real-time reporting capability. We post the most recent 5 days of data from approximately 180 stations as part of our near-real time website (http://ilikai.soest.hawaii.edu/RSL/). At most of these sites, the data are also available for direct download. Real-time data are received via a number of transmission channels. For example, data from UHSLC operated stations are received at the data center within minutes of transmission using the geostationary meteorological satellite system and the GTS. Data from the U.K. stations are received via email and updated within hours of transmission. NOAA CO-OPS data are obtained via the GTS and a backup download from their web site. Data from Chile and other countries that use the GOES are acquired via the GTS and also downloaded from the GOES web site.

As part of the JCOMM SLP-Pac, the UHSLC operates a Specialized Oceanographic Center that produces sea surface topography maps (monthly) and diagnostic time series (quarterly) for the Pacific Ocean. This activity is a continuation of one of the earliest examples of operational oceanography. The analysis includes comparisons of tide gauge and altimeter sea surface elevations that are available at our web site (http://ilikai.soest.hawaii.edu/uhslc/products.html).

The center produces CD-ROMs that mirror the UHSLC web site. These CDs are distributed with the JASL annual data report, shared with all data originators, and sent to other users upon request. Over 100 were distributed again last year.

GCOS Network Status

The UHSLC is working with GLOSS and international partners to bring the 170 stations in the GCOS network into full operational mode, which means having all stations report high quality data in near-real time, with the majority of stations having some sort of vertical datum control via GPS or DORIS. The status of the GCOS network is summarized in Figure 2. In the past year, we've added approximately 17 new GCOS stations into the near-real time data stream, so that 60% of the network is at that capability (72% are at Fast Delivery status or better). We estimate that 77 of the GCOS stations have nearby (< 10 km) GPS or DORIS for datum control. Immediate implementation plans for the GCOS network are described in the FY2008 work plan.

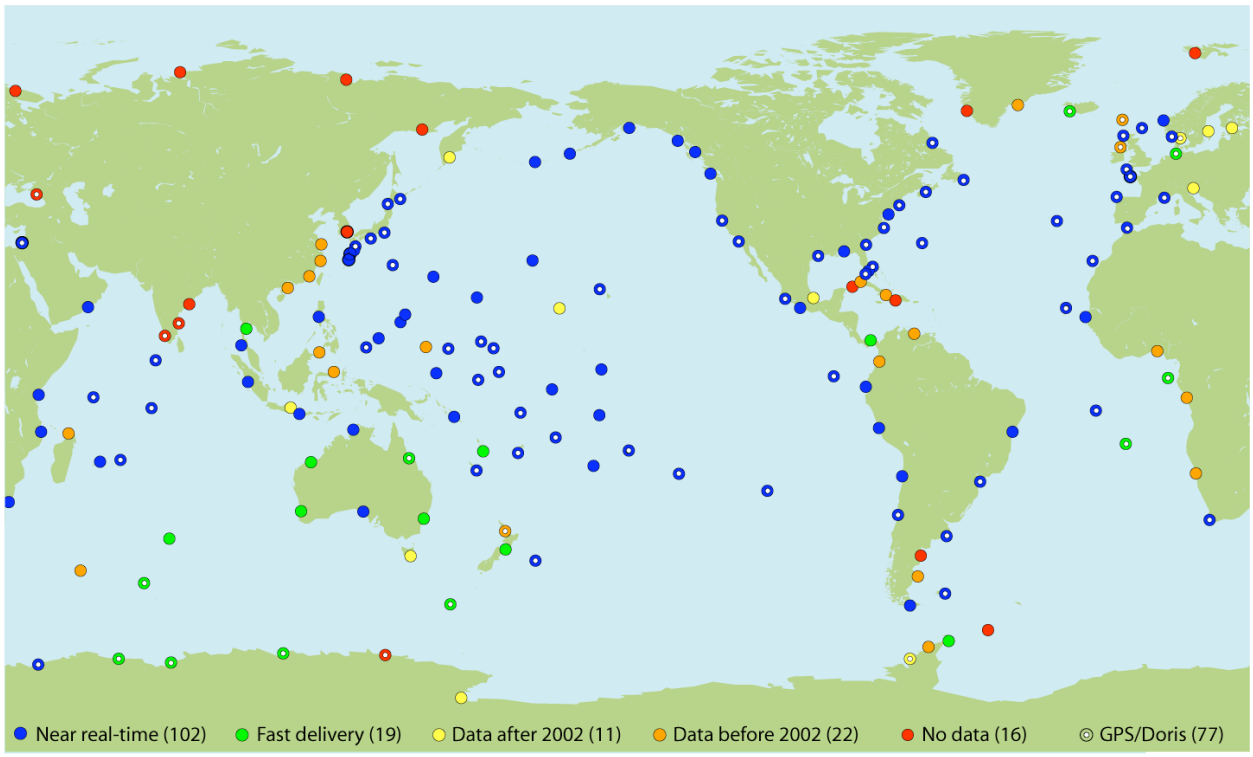

Figure 2. Summary of GCOS station data availability at UHSLC as of November 2007. The data must be sampled at one hour period or shorter. "Near real-time" are typically received within 1 hour, "Fast delivery" within 4-6 weeks.

Research Highlights

Research during FY07 focused on annual reporting of sea level, extreme events, and sea level rise estimates.

The seasonality of extreme sea level events has been quantified and related to tidal and storm forcings. At a surprising number of stations, annual extremes are determined primarily by higher than normal spring tides occurring at the equinoxes or the solstices. Maps of the amplitude and phase of extreme springs tides has been published for a global set of tide gauges. A paper is in press as part of the Aha Hulikoa workshop proceedings.

Estimates of globally averaged sea level from the GCOS or GLOSS networks are subject to errors associated with sparse spatial coverage, varying tide gauge record lengths, and unresolved vertical land motion at each station. An assessment of these errors has been made by comparing estimates from the tide gauge network with more complete averages from altimeter observations and SODA-POP model simulations. Even with simple spatial averaging strategies, the GCOS network does reasonably well in reproducing global sea level variability when the majority of the network is in operation. The results degrade as the number of available stations within latitude bands decreases going back in time, particularly in the southern hemisphere. The impact of land motion corrections on the global sea level estimates is assessed using vertical rates derived from continuous GPS measurements. The error analysis is used to assess global sea level rise trends obtained from the GCOS network and comparisons are made with rates derived from altimetry

and other recent tide gauge based studies. This work was presented at the Ocean Topography Group meeting in Hobart and a manuscript is in preparation.

We are developing a global reference frame for determining vertical land motion at tide gauge locations. This work is now in its final phase, with Michael Bevis at the Ohio State University performing the global analyses of GPS time series. We intend to have maps of land rates at all available GCOS and GLOSS stations by the end of the coming year.

We took part in the third OCO contribution to the BAMS State of the Climate report, describing sea level patterns during 2006, and an update of global sea level rise estimates (Merrifield et al., 2007).

Conferences, Meetings, Expert Panels, and Working Groups

- January 2007 – ICG/IOTWS WG Chairs Steering Group Meeting, Perth 2007.
- February 2007- NOAA IOTWS Project meeting, ITPT meeting, Washington DC.
- March 2007 - Intergovernmental Coordination Group for the Indian Ocean Tsunami Warning and Mitigation System (ICG/IOTWS-IV), Mombassa , Kenya.
- April 2007 – PTWS Officers meeting, Honolulu, Hawaii.
- June 2007 – GLOSS Group of Experts meeting, Paris, France.
- September 2007 - ICG/IOTWS WG2 intersessional meeting, Jakarta, Indonesia
- September 2007 - The 22nd meeting of the Intergovernmental Coordination Group of the Pacific Tsunami Warning System (ICG/PTWS-XXII), Guayaquil, Ecuador
- October 2007 – NOAA PRIDE investigators meeting, Honolulu, Hawaii

PUBLICATIONS AND REPORTS

Brooks, B. A., M. Merrifield, J. Foster, C. L. Werner, F. Gomez, M. Bevis, S. Gill, Space geodetic determination of spatial variability in relative sea level change, Los Angeles basin, *Geophys. Res. Lett.*, 34, L01611, doi:10.1029/2006GL028171, 2007.

Merrifield, M**.,** G.T. Mitchum**,** S. Gill and P. Woodworth, Sea Level *in* State of the Climate in 2006, Arguez, A., ed., *Bull. Amer. Met. Soc.*, **88**, S1-S135, doi:10.1175/bams-88-6-929Mitchum, G.T., R., 2007.

Merrifield, M. A., Y. L. Firing, and J. J. Marra, Annual climatologies of extreme water levels, Aha Hulikoa workshop proceedings, in press, 2007.

Mitchum, G., S. Nerem, M.A. Merrifield and R. Gehrels, 20th Century Sea Level Change Estimates From Tide Gauges and Altimeters, Cambridge University Press (reviewed book chapter), in press, 2007.